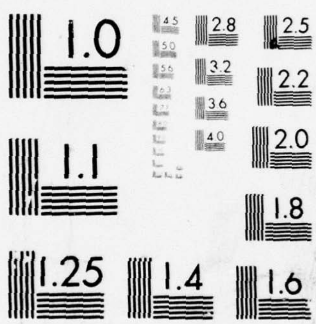
AD-A072 555 GEOLOGICAL SURVEY LAKEWOOD CO WATER RESOURCES DIV F/G 8/8
HYDROLOGIC EFFECTS OF ANNUALLY DIVERTING 131,000 ACRE-FEET OF W--ETC(U)
JAN 79 W M ALLEY, D P BAUER, J E VEENHUIS

UNCLASSIFIED USGS/WRD/WRI-79/020 NL

| OF |

AD
A072555

END
DATE
FILMED
9-79
DDC



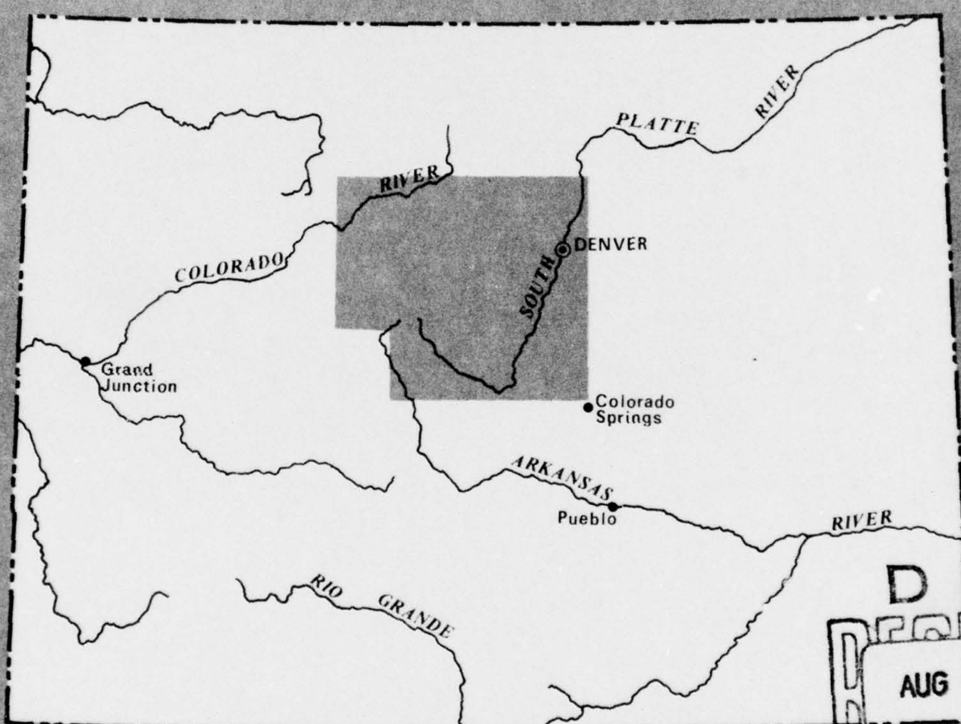
MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

Alley and others--HYDROLOGIC EFFECTS OF ANNUALLY DIVERTING 131,000 ACRE-FEET OF WATER FROM DILLON RESERVOIR, COLO.

HYDROLOGIC EFFECTS OF ANNUALLY DIVERTING 131,000 ACRE-FEET OF WATER FROM DILLON RESERVOIR, CENTRAL COLORADO

U.S. GEOLOGICAL SURVEY



Water Resources Investigations 79-2

Prepared in cooperation with the
U.S. Army Corps of Engineers

BIBLIOGRAPHIC DATA SHEET	1. Report No. USGS/WRD/WRI-79/020	2.	3. Recipient's Accession No.
4. Title and Subtitle HYDROLOGIC EFFECTS OF ANNUALLY DIVERTING 131,000 ACRE-FEET OF WATER FROM DILLON RESERVOIR, CENTRAL COLORADO			5. Report Date January 1979
			6.
7. Author(s) W. M. Alley, D. P. Bauer, J. E. Veenhuis, and Robert Brennan			8. Performing Organization Rept. No. USGS/WRI 79-2
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division Denver Federal Center, Box 25046, Mail Stop 415 Lakewood, Colorado 80225			10. Project/Task/Work Unit No.
			11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division Denver Federal Center, Box 25046, Mail Stop 415 Lakewood, Colorado 80225			13. Type of Report & Period Covered Final
			14.

15. Supplementary Notes

Prepared in cooperation with the U.S. Army Corps of Engineers

16. Abstracts

Because of the increased demands for water in eastern Colorado, principally in the urbanizing Denver metropolitan area, increased diversions of water from Dillon Reservoir are planned. Estimates of end-of-month storage in Dillon Reservoir, assuming the reservoir was in place and 131,000 acre-feet of water were diverted from the reservoir each year, were reconstructed by mass balance for the 1931-77 water years. Based on the analysis, the annual maximum end-of-month drawdown below the elevation at full storage would have averaged 54 feet. The maximum end-of-month drawdown below the elevation at full storage would have been 171 feet.

The mean-annual discharge-weighted dissolved-solids concentrations in the Colorado River near Glenwood Springs and Cameo, Colo., and Cisco, Utah, for the 1942-77 water years, were computed assuming an annual diversion of 131,000 acre-feet of water from Dillon Reservoir. The average increases in the dissolved-solids concentrations with the 131,000-acre-foot diversion were 15 to 16 milligrams per liter at the three sites.

17. Key Words and Document Analysis. 17a. Descriptors

Colorado, Surface-water availability, Water resources, Water storage, Water supply

17b. Identifiers/Open-Ended Terms

Colorado River basin, Dillon Reservoir, Dissolved solids, Reservoir analysis, Summit County

Approved for public release; distribution unlimited.

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 22
No restriction on distribution Prepared for NTIS by U.S. Geological Survey, WRD	20. Security Class (This Page UNCLASSIFIED	22. Price

BIBLIOGRAPHIC DATA SHEET 14

1. Report No. USGS/WRD/WRI-79/020, USGS/WRI-79-21

2.

3. Recipient's Accession No.

4. Title and Subtitle
6 HYDROLOGIC EFFECTS OF ANNUALLY DIVERTING 131,000 ACRE-FEET OF WATER FROM DILLON RESERVOIR, CENTRAL COLORADO.

5. Report Date 11 Janu[redacted]979

6.

7. Author(s)
W. M. Alley, D. P. Bauer, J. E. Veenhuis, and Robert Brennan

8. Performing Organization Rept. No. USGS/WRI-79-2

9. Performing Organization Name and Address
U.S. Geological Survey, Water Resources Division
Denver Federal Center, Box 25046, Mail Stop 415
Lakewood, Colorado 80225

10. Project/Task/Work Unit No.

11. Contract/Grant No. 12 25p.

12. Sponsoring Organization Name and Address
U.S. Geological Survey, Water Resources Division
Denver Federal Center, Box 25046, Mail Stop 415
Lakewood, Colorado 80225

13. Type of Report & Period Covered 9 Final rept.

14.

15. Supplementary Notes
Prepared in cooperation with the U.S. Army Corps of Engineers

16. Abstracts
Because of the increased demands for water in eastern Colorado, principally in the urbanizing Denver metropolitan area, increased diversions of water from Dillon Reservoir are planned. Estimates of end-of-month storage in Dillon Reservoir, assuming the reservoir was in place and 131,000 acre-feet of water were diverted from the reservoir each year, were reconstructed by mass balance for the 1931-77 water years. Based on the analysis, the annual maximum end-of-month drawdown below the elevation at full storage would have averaged 54 feet. The maximum end-of-month drawdown below the elevation at full storage would have been 171 feet.

The mean-annual discharge-weighted dissolved-solids concentrations in the Colorado River near Glenwood Springs and Cameo, Colo., and Cisco, Utah, for the 1942-77 water years, were computed assuming an annual diversion of 131,000 acre-feet of water from Dillon Reservoir. The average increases in the dissolved-solids concentrations with the 131,000-acre-foot diversion were 15 to 16 milligrams per liter at the three sites.

17. Key Words and Document Analysis. 17a. Descriptors

Colorado, Surface-water availability, Water resources, Water storage, Water supply

10 William M./Alley, Daniel P./Bauer, Jack E./Veenhuis Robert/Brennan

17b. Identifiers/Open-Ended Terms

Colorado River basin, Dillon Reservoir, Dissolved solids, Reservoir analysis, Summit County

Approved for public release; distribution unlimited.

17c. COSATI Field/Group 411324

18. Availability Statement
No restriction on distribution
Prepared for NTIS by U.S. Geological Survey, WRD

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages 22

22. Price

INSTRUCTIONS FOR COMPLETING FORM NTIS-35 (Bibliographic Data Sheet based on COSATI Guidelines to Format Standards for Scientific and Technical Reports Prepared by or for the Federal Government, PB-180 600).

1. **Report Number.** Each individually bound report shall carry a unique alphanumeric designation selected by the performing organization or provided by the sponsoring organization. Use uppercase letters and Arabic numerals only. Examples FASEB-NS-73-87 and FAA-RD-73-09.

2. Leave blank.

3. **Recipient's Accession Number.** Reserved for use by each report recipient.

4. **Title and Subtitle.** Title should indicate clearly and briefly the subject coverage of the report, subordinate subtitle to the main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific volume.

5. **Report Date.** Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected (e.g., date of issue, date of approval, date of preparation, date published).

6. **Performing Organization Code.** Leave blank.

7. **Author(s).** Give name(s) in conventional order (e.g., John R. Doe, or J.Robert Doe). List author's affiliation if it differs from the performing organization.

8. **Performing Organization Report Number.** Insert if performing organization wishes to assign this number.

9. **Performing Organization Name and Mailing Address.** Give name, street, city, state, and zip code. List no more than two levels of an organizational hierarchy. Display the name of the organization exactly as it should appear in Government indexes such as Government Reports Index (GRI).

10. **Project/Task/Work Unit Number.** Use the project, task and work unit numbers under which the report was prepared.

11. **Contract/Grant Number.** Insert contract or grant number under which report was prepared.

12. **Sponsoring Agency Name and Mailing Address.** Include zip code. Cite main sponsors.

13. **Type of Report and Period Covered.** State interim, final, etc., and, if applicable, inclusive dates.

14. **Sponsoring Agency Code.** Leave blank.

15. **Supplementary Notes.** Enter information not included elsewhere but useful, such as: Prepared in cooperation with . . . Translation of . . . Presented at conference of . . . To be published in . . . Supersedes . . . Supplements . . . Cite availability of related parts, volumes, phases, etc. with report number.

16. **Abstract.** Include a brief (200 words or less) factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **Key Words and Document Analysis. (a). Descriptors.** Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.
    (b). Identifiers and Open-Ended Terms. Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.
    (c). COSATI Field/Group. Field and Group assignments are to be taken from the 1964 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the primary Field/Group assignment(s) will be the specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **Distribution Statement.** Denote public releasability, for example "Release unlimited", or limitation for reasons other than security. Cite any availability to the public, other than NTIS, with address, order number and price, if known.

19 & 20. **Security Classification.** Do not submit classified reports to the National Technical Information Service.

21. **Number of Pages.** Insert the total number of pages, including introductory pages, but excluding distribution list, if any.

22. **NTIS Price.** Leave blank.

8

HYDROLOGIC EFFECTS OF ANNUALLY DIVERTING 131,000 ACRE-FEET OF WATER FROM DILLON RESERVOIR, CENTRAL COLORADO

By William M. Alley, Daniel P. Bauer, Jack E. Veenhuis, and Robert Brennan

---

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 79-2

Prepared in cooperation with the
U.S. Army Corps of Engineers

January 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Denver Federal Center
Lakewood, CO 80225

CONTENTS

ILLUSTRATIONS

TABLES

METRIC CONVERSIONS

Multiply inch-pound unit	*By*	*To obtain metric unit*
inch	25.40	millimeter
	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
mile per hour	1.609	kilometer per hour
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
millibar	100.0	newton per square meter

HYDROLOGIC EFFECTS OF ANNUALLY DIVERTING 131,000 ACRE-FEET OF WATER FROM DILLON RESERVOIR, CENTRAL COLORADO

By William M. Alley, Daniel P. Bauer, Jack E. Veenhuis, and Robert Brennan

ABSTRACT

Because of the increased demands for water in eastern Colorado, principally in the urbanizing Denver metropolitan area, increased diversions of water from Dillon Reservoir are planned. The U.S. Army Corps of Engineers requested the U.S. Geological Survey to determine the hydrologic effects of annually diverting 131,000 acre-feet of water from Dillon Reservoir.

Estimates of end-of-month storage in Dillon Reservoir, assuming the reservoir was in place and 131,000 acre-feet of water were diverted from the reservoir each year, were reconstructed by mass balance for the 1931-77 water years. Based on the analysis, the annual maximum end-of-month drawdown below the elevation at full storage would have averaged 54 feet. The maximum end-of-month drawdown below the elevation at full storage would have been 171 feet.

The mean-annual discharge-weighted dissolved-solids concentrations in the Colorado River near Glenwood Springs and Cameo, Colo., and Cisco, Utah, for the 1942-77 water years, were computed assuming an annual diversion of 131,000 acre-feet of water from Dillon Reservoir. The average increases in the dissolved-solids concentrations with the 131,000-acre-foot diversion were 15 to 16 milligrams per liter at the three sites.

INTRODUCTION

Because of the increased demands for water in eastern Colorado, principally in the urbanizing Denver metropolitan area, increased diversions of water from Dillon Reservoir are planned (U.S. Department of the Interior, 1977). The U.S. Army Corps of Engineers, who are involved with the implementation of these diversions, requested the U.S. Geological Survey to determine the hydrologic effects of annually diverting 131,000 acre-ft of water from Dillon Reservoir.

On the basis of the planned increases in transmountain diversions from Dillon Reservoir, the purposes of this study were to determine the effects of the diversions on the storage in Dillon Reservoir and to determine the effects of the diversions on the dissolved-solids concentrations in the Colorado River near Glenwood Springs and Cameo, Colo., and Cisco, Utah. The effects on storage were to be determined on a monthly basis, and the effects on dissolved-solids concentrations were to be determined on a yearly basis.

DESCRIPTION OF STUDY AREA

Dillon Reservoir is located in the Blue River basin west of the Continental Divide, approximately 70 mi west of Denver, Colo. (fig. 1). The spillway elevation of the dam is 9,017 ft and the reservoir has an active storage[1] capacity of 254,036 acre-ft with a full-capacity surface area of 3,233 acres and maximum depth of 188 ft. The relationship of surface area and storage to elevation of Dillon Reservoir is shown in figure 2. The dam was completed in 1963 and the reservoir filled during 1964 and 1965. Major tributaries to the reservoir are the Blue and Snake Rivers and Tenmile Creek. The drainage area upstream from the dam is 335 mi^2. Water is diverted from Dillon Reservoir to the North Fork South Platte River by way of the Harold D. Roberts Tunnel.

Upstream from Dillon Reservoir, water is diverted from the Blue River basin through the Hoosier Pass Tunnel and the Boreas Pass ditch to the South Platte River basin (fig. 1). Water has been diverted through the Hoosier Pass Tunnel since June 1952. Annual diversions have averaged 7,900 acre-ft. Water has been diverted through the Boreas Pass ditch since 1909. Annual diversions have averaged 100 acre-ft. Water was diverted from Tenmile Creek through the Fremont Pass ditch to the Arkansas River basin from 1929 to 1943. Annual diversions averaged 1,230 acre-ft. Water for power generation, which averaged 17,000 acre-ft per year, was diverted from the Snake River prior to December 15, 1959. The water was returned to the Blue River downstream from Dillon Reservoir.

Green Mountain Reservoir is located approximately 21 mi downstream from Dillon Reservoir. Water stored in Green Mountain Reservoir is used for irrigation and for power generation. Water from Green Mountain Reservoir flows into the Colorado River about 15 mi downstream from the dam.

SURFACE-WATER RIGHTS

Surface water in the Blue River basin is presently (1978) being used by a variety of users both within and outside of the basin. As noted by Knudsen and Danielson (1977), Colorado uses the doctrine of Prior Appropriation or

---

[1]Active storage is storage above the elevation of the bottom or invert of the reservoir outlet to the Blue River (8,829 ft). The term "storage" as used in this report will refer to active storage.

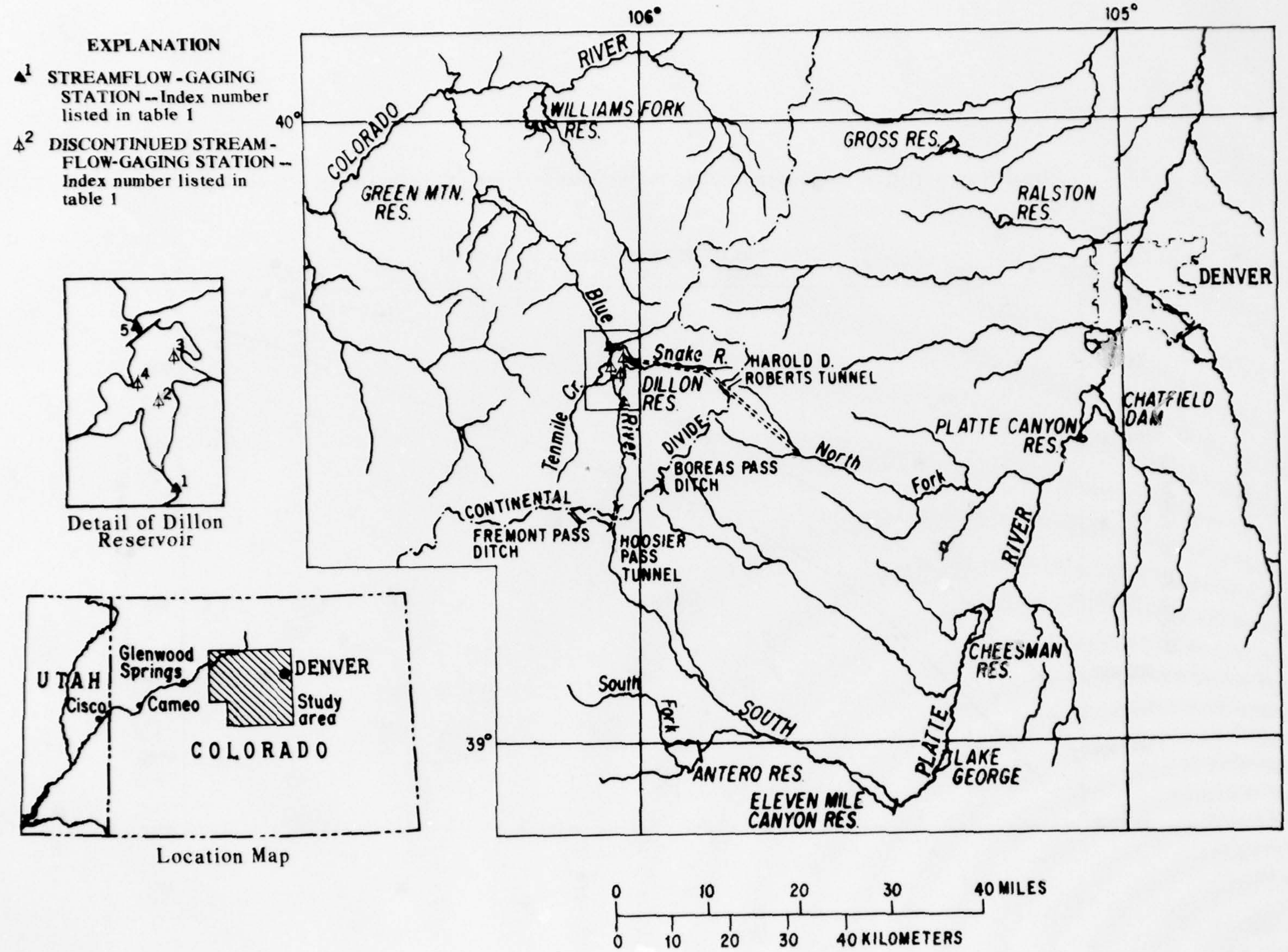


Figure 1.--Location of study area.

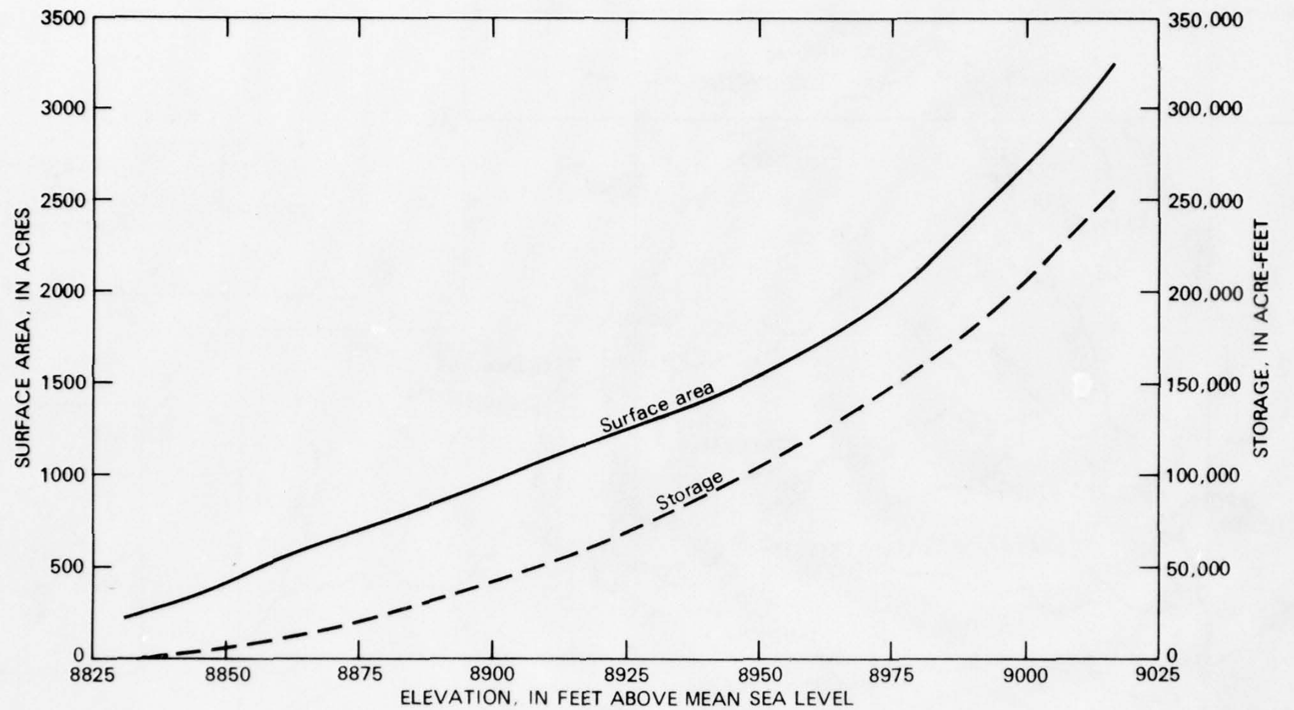


Figure 2.--Relationship of surface area and storage to elevation of Dillon Reservoir.

"first in time, first in right" in determining and administrating surface-water rights.

As long as there is sufficient water available to meet all demands there are few problems. But, as noted by Knudsen and Danielson (1977), "If there is insufficient water to meet all demands, then the priority date would be used to allocate the available water as follows: those priorities most recent in time (that is, junior priorities) must allow sufficient surface water to pass by their points of diversion in order to let downstream priorities earlier in time (that is, senior priorities) receive the water due them according to their decree as adjudicated by the judicial system."

Surface-water rights decreed to diversions through the Hoosier Pass Tunnel and to power generation and storage in Green Mountain Reservoir are senior to water rights decreed to diversions through the Harold D. Roberts Tunnel. These surface-water rights were considered in the monthly mass-balance analysis. Several relatively small diversions within the basin and diversions through the Boreas Pass ditch were not considered in the analysis.

MONTHLY MASS-BALANCE ANALYSIS OF RESERVOIR STORAGE

Approach

Hypothetical monthly mass balances of storage in Dillon Reservoir, assuming an annual diversion of 131,000 acre-ft of water, were reconstructed for water years[2] 1931-77 using available data. The reconstructed data may be used to predict future effects of an annual diversion of 131,000 acre-ft of water on storage in and outflow from Dillon Reservoir, assuming that future hydrologic conditions will be similar to the historic hydrologic conditions on which the analysis is based. The mass-balance analysis was based on the principle of continuity as expressed by the equation:

$$S_i = S_{i-1} + I_i - D_i - E_i - O_i, \qquad (1)$$

where:

S_i=reservoir storage at the end of the current month, i, in acre-feet;

S_{i-1}=reservoir storage at the end of the previous month, $i-1$, in acre-feet;

I_i=inflow to the reservoir during month i, in acre-feet;

D_i=transmountain diversion from the reservoir during month i, in acre-feet;

E_i=net evaporation from the reservoir during month i, in acre-feet; and

O_i=downstream releases from the reservoir during month i, in acre-feet.

---

[2]A water year begins on October 1, ends on September 30, and is designated by the calendar year in which it ends.

Period of Analysis

The availability of streamflow data in the vicinity of Dillon Reservoir was the governing factor in selecting a period of analysis. Streamflow data used in this study were based on streamflow records collected by the U.S. Geological Survey. Descriptions of the streamflow-gaging stations are shown in table 1, and the stations are located on figure 1.

The longest period for which adequate streamflow records were available to define monthly inflow to Dillon Reservoir was for the 1930-77 water years. Streamflow during this period was compared to streamflow during the 1912-77 water years using the "natural" streamflow at station 2 (Blue River at Dillon) (fig. 1 and table 1).

"Natural" streamflow at station 2 was determined as follows: Monthly interstation flow coefficients between stations 1 (Blue River near Dillon) and 2 (Blue River at Dillon) were derived using the October 1957-April 1961 records from both stations. The streamflow record for station 2 was then extended through water year 1977 using the monthly interstation flow coefficients and monthly streamflow at station 1. To establish a "natural" streamflow record for station 2, the transmountain diversions through the Hoosier Pass Tunnel, which began in 1952, were then added to the streamflow at station 2.

The resulting annual "natural" streamflow and cumulative departure from the average annual "natural" streamflow at station 2 are shown in figure 3. During periods of above-average streamflow, the cumulative departure from the average will increase while, during periods of below-average streamflow, the cumulative departure from the average will decrease. The data in figure 3 indicate that inflow to Dillon Reservoir generally would have been above average during water years 1912-30 and often would have been below average thereafter. If Dillon Reservoir had been in place from water years 1912-77 and 131,000 acre-ft of water had been diverted each year, then reservoir storage probably would have been lowest during the periods of steepest decline of the curve showing the cumulative departure from the average (fig. 3). Thus, the period when reservoir storage would have been lowest was apparently after the 1930 water year and probably would have occurred during the mid-1950's or late 1960's. During the 1925-30 water years, the Blue River annual flowrates near the Dillon Reservoir's present location were above average (see fig. 3). For this reason, the analysis was begun with the 1931 water year assuming the reservoir was in place and full at this time.

Data Requirements

Solving the mass-balance equation (equation 1) required the following data: Monthly inflows to the reservoir, monthly diversions from the reservoir, monthly net evaporation from the reservoir, and monthly downstream releases from the reservoir.

Table 1.--*Description of streamflow-gaging stations*

Index number on figure 1	U.S. Geological Survey downstream order number	Station name	Period of record	Drainage area (square miles)	Remarks
1	09046600	Blue River near Dillon.	October 1957-Present-----	119	Transmountain diversions upstream from station through Boreas Pass ditch and Hoosier Pass Tunnel.
2	09047000	Blue River at Dillon.	October 1910-April 1961--	128	Do.
3	09048000	Snake River at Dillon.	October 1910-September 1919, October 1929-April 1964.	90.9	Diversion for power 6 miles upstream from station prior to December 15, 1959; water returned to Blue River downstream from station 5.
4	09050500	Tenmile Creek at Dillon.	October 1910-September 1919, October 1929-April 1961.	111	Transmountain diversion upstream from station through Fremont Pass Pass ditch, 1929-43.
5	09050700	Blue River below Dillon.	January 1960-Present-----	335	Transmountain diversions upstream from station through Boreas Pass ditch and Hoosier Pass Tunnel. Flow regulated by Dillon Reservoir,0.3 mile upstream, since September 3, 1963.

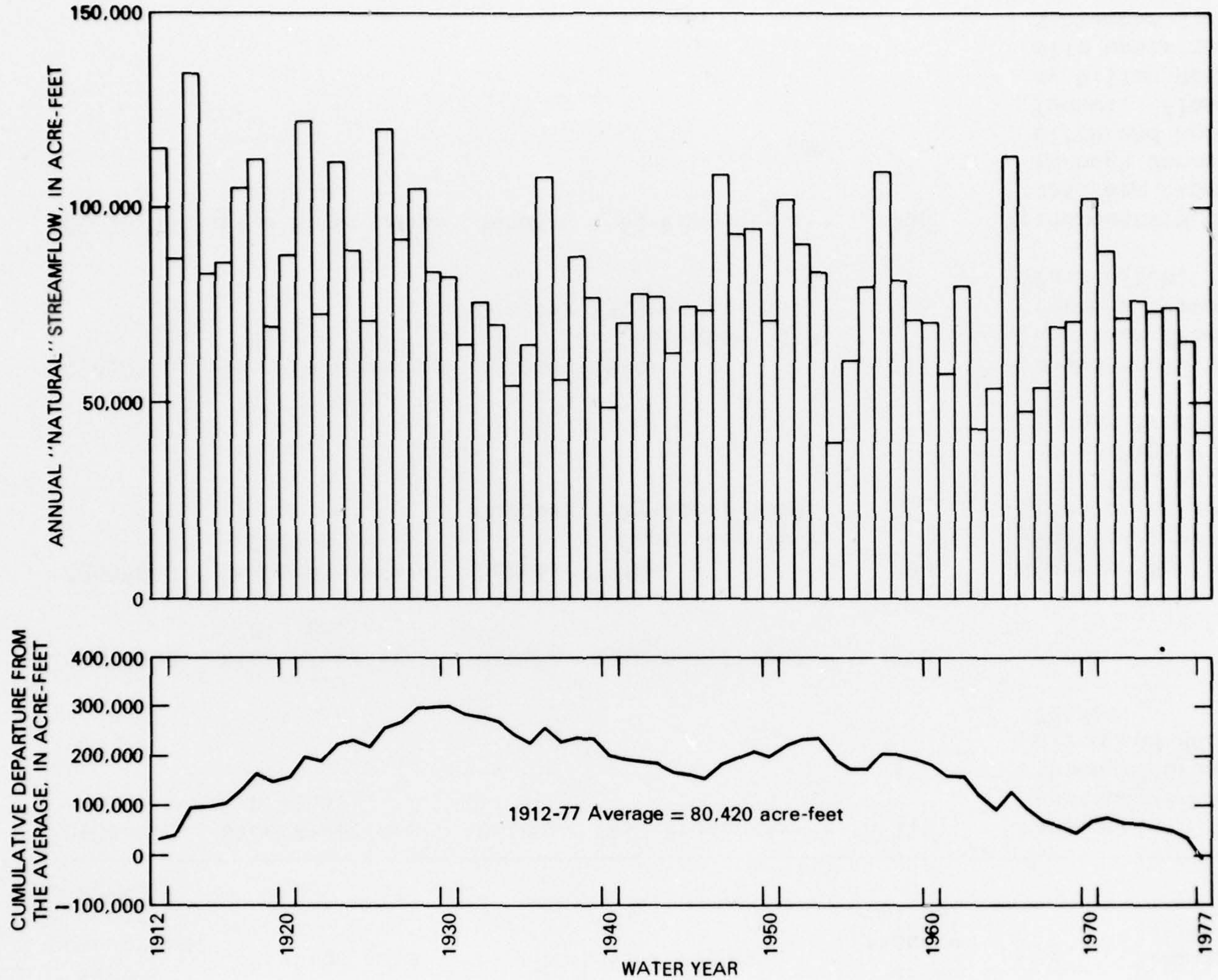


Figure 3.--Annual "natural" streamflow of the Blue River at Dillon and cumulative departure from the average (1912-77 water years).

Monthly Inflows

Monthly inflows to Dillon Reservoir from October 1930 through December 1959 were determined by first adding the monthly flows at stations 2, 3, and 4 (fig. 1 and table 1). Then, the average monthly diversions through Hoosier Pass Tunnel during the 1952-77 water years were subtracted from the accumulated monthly flows prior to the 1952 water year. Finally, monthly diversions through Fremont Pass ditch and monthly diversions from the Snake River for power generation were added to the accumulated monthly flows. Streamflow records for station 5 were used to determine monthly inflows from January 1960 through August 1963. Monthly diversions through Harold D. Roberts Tunnel, monthly downstream releases, and monthly changes in storage were known for the actual reservoir operation between September 1963 and September 1977. These data along with estimates of monthly net evaporation, as developed in a following section, were used to calculate monthly inflows to Dillon Reservoir during this period using the following equation:

$$I_i=D_i+E_i+O_i+(S_i-S_{i-1}), \qquad (2)$$

where all variables are as defined in equation 1.

Monthly Diversions

An annual diversion of 131,000 acre-ft was used according to the proposed monthly diversion schedule for the Harold D. Roberts Tunnel in 1988. These data, which were obtained from the U.S. Bureau of Reclamation (J. D. Hall, written commun., 1978), are shown in table 2.

The bottom or invert of the Harold D. Roberts Tunnel at Dillon Reservoir is at an elevation of 8,846 ft. If the end-of-month reservoir elevation using equation 1 was less than 8,846 ft, the diversion for that month was decreased in the analysis until the end-of-month reservoir elevation was at 8,846 ft.

Monthly Net Evaporation

Net evaporation is evaporation minus precipitation on the reservoir surface. Monthly net evaporation from Dillon Reservoir was computed using the following equation:

$$E_i=(EV_i-P_i)\cdot\bar{A}_i/12, \qquad (3)$$

where:

E_i=net evaporation from the reservoir during month i, in acre-feet;

EV_i=evaporation during month i, in inches;

P_i=precipitation during month i, in inches; and

$\bar{A}_i$=average reservoir surface area during month i, in acres.

Table 2.--*Proposed monthly diversion schedule for Harold D. Roberts Tunnel used in mass-balance analysis*

[J. D. Hall, written commun., 1978]

Month	Diversion, in acre-feet
October	13,800
November	10,200
December	10,200
January	10,100
February	8,800
March	9,600
April	12,100
May	12,100
June	3,900
July	9,400
August	17,100
September	13,700
Total	131,000

Monthly evaporation (EV_i in equation 3) for 1969-71 was measured during energy-budget studies conducted by Ficke, Adams, and Danielson (1977). Monthly evaporation for 1971-77 was computed using a mass-transfer equation derived by Harbeck (1962):

$$EV_i = N \cdot u \cdot (e_o - e_a)/2.54, \tag{4}$$

where:

N=an empirical coefficient;

u=average wind speed at 2 meters above water surface, in miles per hour;

e_o=saturation vapor pressure of air at temperature of the water surface, in millibars;

e_a=vapor pressure of the air, in millibars; and

2.54=conversion factor (centimeters per inch).

On the basis of the energy-budget studies of 1969-71, the N coefficient for Dillon Reservoir was estimated to be 0.00796 (Ficke and others, 1977). This value, along with wind-speed and vapor-pressure data, was used in equation 4 to compute monthly evaporation for 1971-77. Prior to 1969, monthly evaporation rates were assumed to be the average monthly values obtained for 1969-77.

Monthly precipitation data (P_i in equation 3) for the entire period of analysis (1931-77 water years) were obtained from the U.S. Environmental Data Service (1966-72) and the U.S. Weather Bureau (1930 and 1961-66; 1954; 1964).

Monthly Downstream Releases

Stipulations for the operation of Dillon Reservoir require release of inflow to the reservoir or 50 ft^3/s, whichever is less, or "small" flows in times of water shortage (U.S. Department of the Interior, 1977). Therefore, the minimum allowable downstream release from Dillon Reservoir during a month was set at the inflow for the month or 50 ft^3/s, whichever was less. During high flow months (June to August) occasional uncontrolled releases (spills) occur as a result of a maximum reservoir storage of 254,036 acre-ft. Many times, during August and September, release of additional water from Dillon Reservoir was required to meet the decreed water rights for Green Mountain Reservoir.

The additional releases required to meet the decreed water rights for Green Mountain Reservoir were determined as follows. During the mass-balance analysis, the sum of the spills from Dillon Reservoir for the water year plus the local inflow between Dillon and Green Mountain Reservoirs during May, June, and July was computed. Local inflows between Dillon and Green Mountain Reservoirs were computed by subtracting the historic streamflows of the Blue River at station 5 or the sum of the historic streamflows at stations 2, 3, and 4 (U.S. Geological Survey, 1954, 1964, 1961-74, 1975-76, 1977) from the historic inflows to Green Mountain Reservoir (J. D. Hall, written commun., 1978).

The U.S. Bureau of Reclamation estimated that the sum of spills plus local inflow during May, June, and July should equal at least 110,000 acre-ft in order to meet water requirements for Green Mountain Reservoir (J. D. Hall, written commun., 1978). Any deficit was reduced by additional releases from Dillon Reservoir, so long as these releases did not exceed the total 12-month inflow to Dillon Reservoir during the preceding year. These additional releases began in August in increments of as much as 25,000 acre-ft per month until the deficit was eliminated.

RESULTS OF MASS-BALANCE ANALYSIS

The maximum and minimum end-of-month reservoir storage, surface area, and elevation that would have occurred during each water year are shown in figure 4. The data indicate considerable fluctuation in reservoir storage would have occurred during the period analyzed. The average annual minimum and the minimum end-of-month reservoir elevation, surface area, and storage are listed in table 3.

The percentage of time that indicated end-of-month elevations of Dillon Reservoir would have been equaled or exceeded is shown in figure 5. For

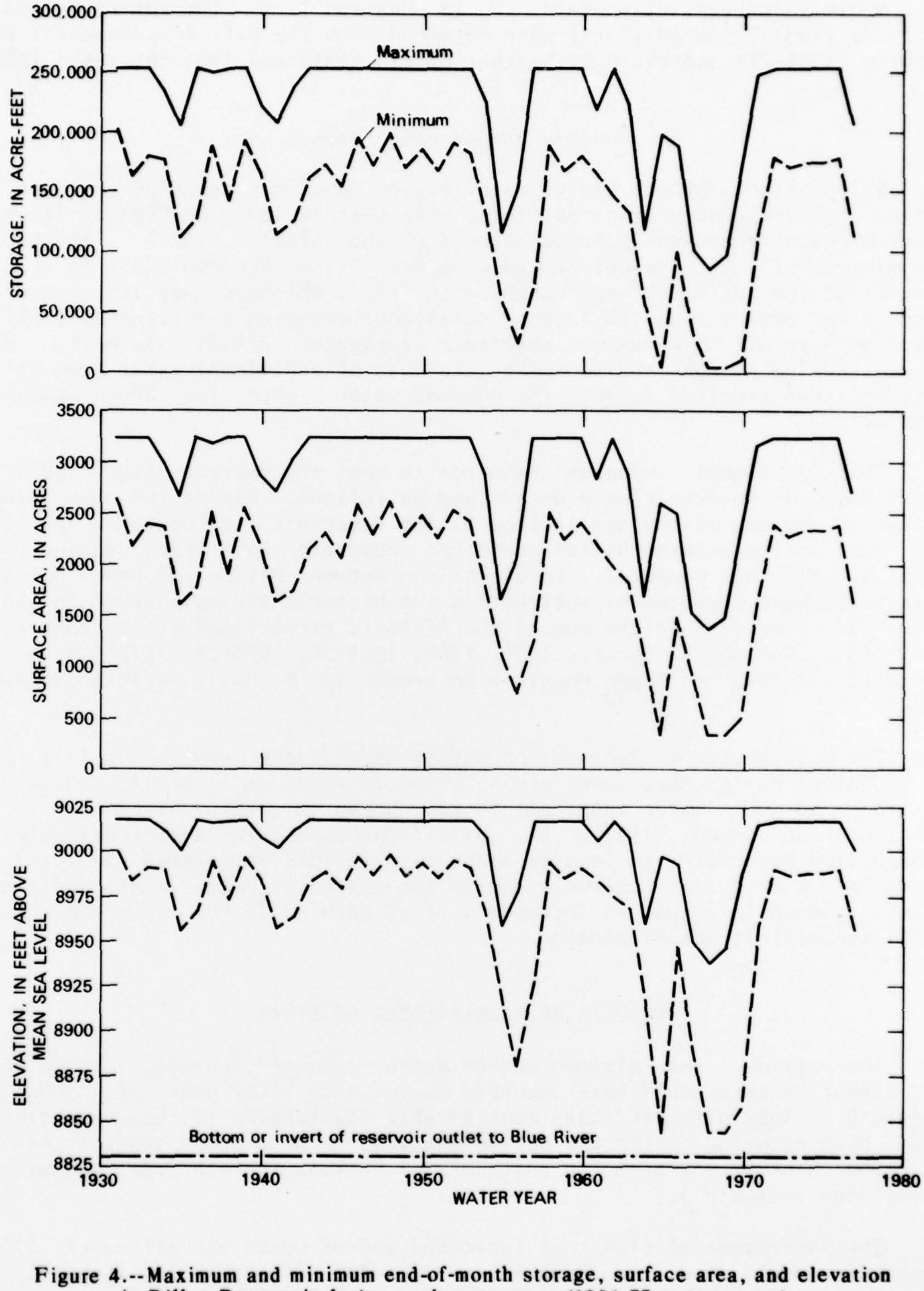


Figure 4.--Maximum and minimum end-of-month storage, surface area, and elevation in Dillon Reservoir during each water year (1931-77 water years).

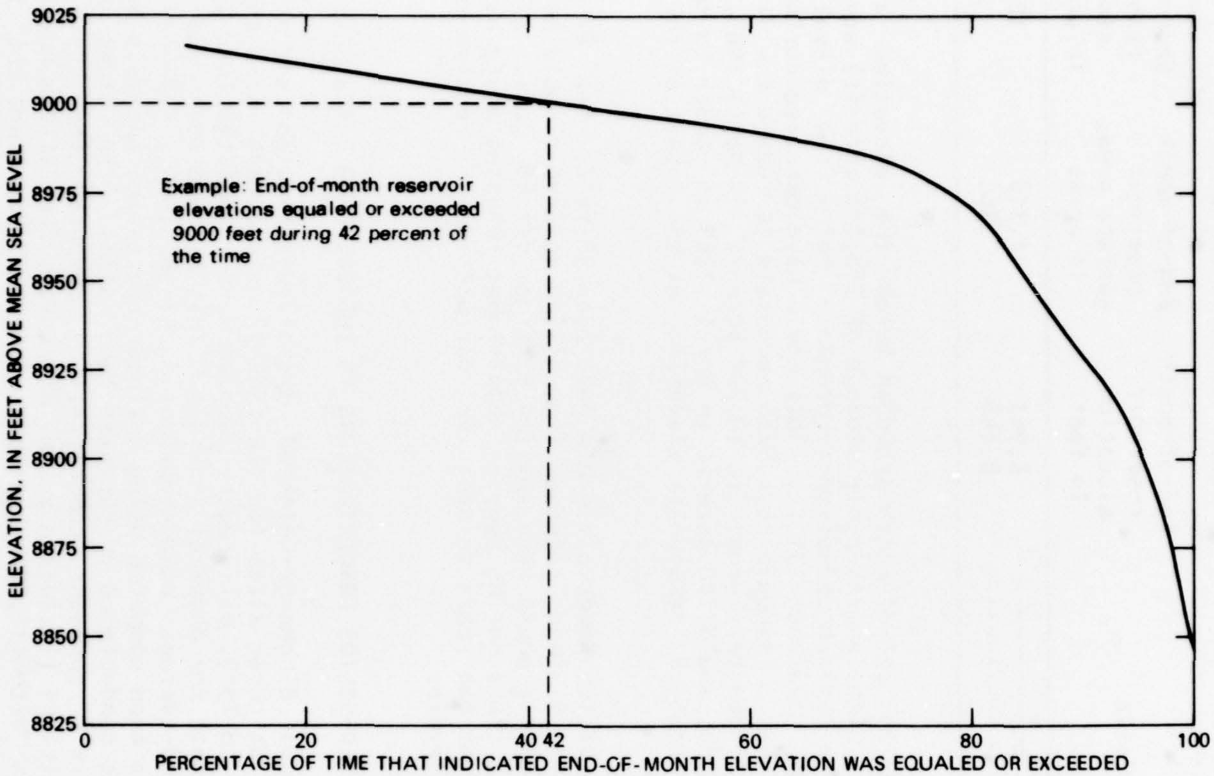


Figure 5.--Percentage of time that indicated end-of-month elevations of Dillon Reservoir were equaled or exceeded (1931-77 water years).

example, figure 5 indicates that 42 percent of the time the end-of-month elevation of Dillon Reservoir would have equaled or exceeded 9,000 ft.

Table 3.--*Minimum end-of-month reservoir elevation, surface area, and storage (1931-77 water years)*

Characteristic	End-of-month reservoir elevation, in feet	End-of-month reservoir surface area, in acres	End-of-month reservoir storage, in acre-feet
Average annual minimum---------	8,963	1,718	124,035
Minimum------------------------	8,846	366	4,845

The annual maximum end-of-month drawdown below the elevation at full storage (9,017 ft with a reservoir storage of 254,036 acre-ft) would have averaged 54 ft. The maximum end-of-month drawdown below the elevation at full storage would have been 171 ft. This would have occurred during April 1965, 1968, and 1969. It would have been necessary to reduce the diversion through Harold D. Roberts Tunnel to 10,700 acre-ft in April 1965, 6,300 acre-ft in April 1968, and 8,200 acre-ft in April 1969 in order to maintain the minimum end-of-month reservoir elevation at the invert of the tunnel (8,846 ft).

Releases from Dillon Reservoir would have been 50 ft^3/s for 82 percent of the time. The minimum release from Dillon Reservoir would have been 42 ft^3/s. The reservoir would have spilled 19 times during June, 27 times during July, and 5 times during August. Additional releases would have been required during 19 of the years to meet the decreed water requirements of Green Mountain Reservoir.

DISSOLVED-SOLIDS CONCENTRATIONS IN THE COLORADO RIVER

The mean-annual discharge-weighted dissolved-solids concentrations in the Colorado River at three sites for the 1942-77 water years are shown in figure 6. Prior to 1969, daily water samples were composited into three or more samples per month for chemical analysis. This allowed for computation of annual weighted-average concentrations. Since 1969, average annual concentrations have been computed using a linear-regression analysis of daily records of specific conductance versus dissolved solids. The values noted as "Historic" in figure 6 represent concentrations computed for these sites under actual conditions (including actual diversions from Dillon Reservoir). The values noted as "With 131,000 acre-feet diversion" represent the concentrations computed for these sites if 131,000 acre-ft of water with a dissolved-solids concentration of 100 mg/L (milligrams per liter) had been diverted from the Blue River basin each year. During dry years, some portion of the diversions through the Harold D. Roberts Tunnel will come from water

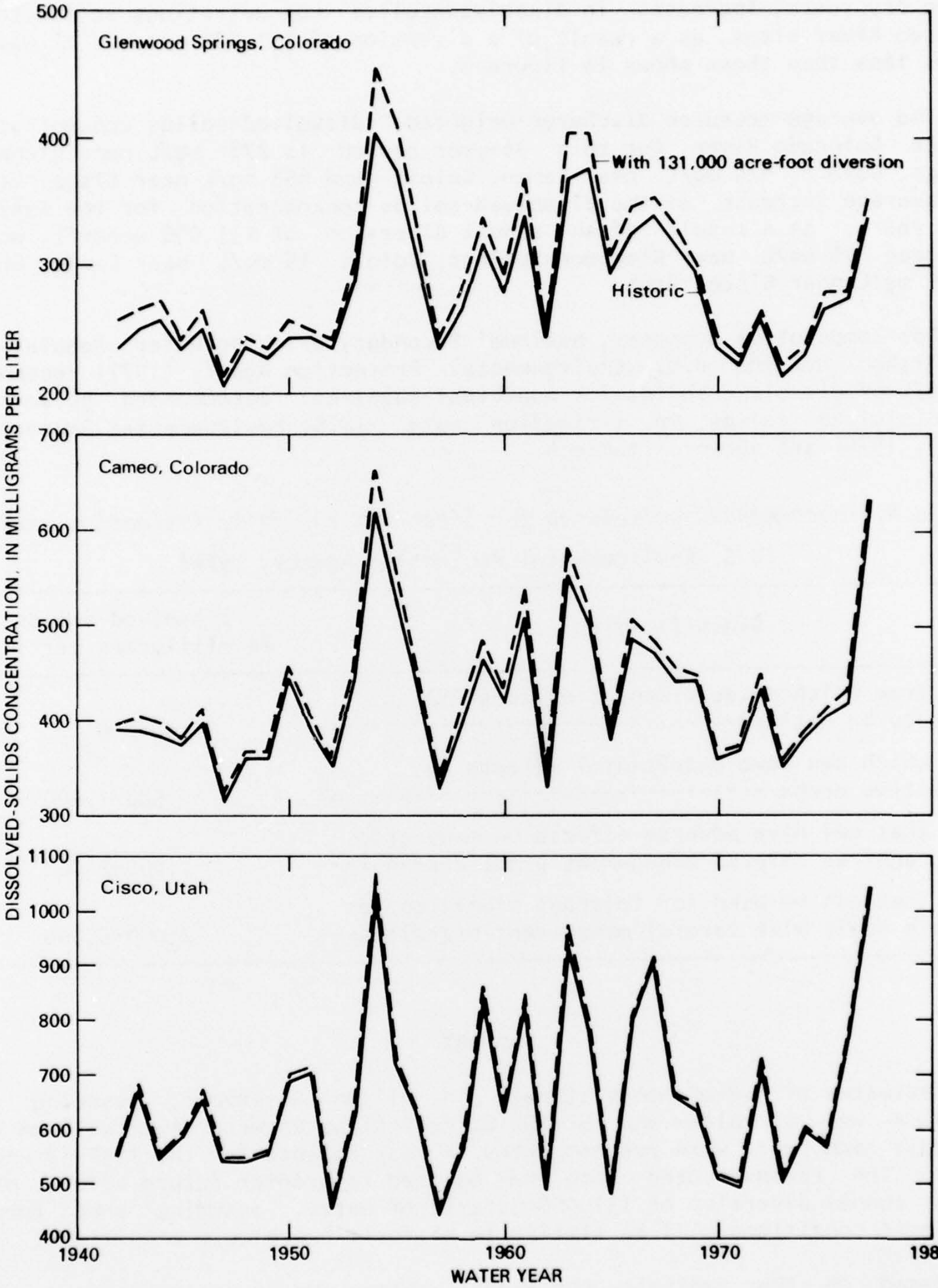


Figure 6.--Dissolved-solids concentrations (mean-annual discharge-weighted) at selected sites on the Colorado River (1942-77 water years).

held in storage at Dillon Reservoir from previous wetter years. Therefore, during dry years, increases in dissolved-solids concentrations at the three Colorado River sites, as a result of a diversion of 131,000 acre-ft of water, may be less than those shown in figure 6.

The average measured discharge-weighted, dissolved-solids concentration for the Colorado River for this 36-year period is 278 mg/L near Glenwood Springs, Colo.; 424 mg/L near Cameo, Colo.; and 653 mg/L near Cisco, Utah. The average increase of the dissolved-solids concentration for the 1942-77 water years, as a result of an annual diversion of 131,000 acre-ft, would have been 16 mg/L near Glenwood Springs, Colo.; 15 mg/L near Cameo, Colo.; and 15 mg/L near Cisco, Utah.

For comparative purposes, National Secondary Drinking Water Regulations established by the U.S. Environmental Protection Agency (1977) recommend 500 mg/L of dissolved solids for municipal supplies. Recommended guidelines for dissolved solids in irrigation water (U.S. Environmental Protection Agency, 1976) are shown in table 4.

Table 4.--*Recommended guidelines for dissolved solids in irrigation water*

[U.S. Environmental Protection Agency, 1976]

Classification	Dissolved solids, in milligrams per liter
Water from which no detrimental effects will usually be noticed------------------------------	500
Water which can have detrimental effects on sensitive crops---------------------------------	500-1,000
Water that may have adverse effects on many crops and requires careful management practices--------	1,000-2,000
Water that can be used for tolerant plants on permeable soils with careful management practices---	2,000-5,000

SUMMARY

Estimates of end-of-month storage in Dillon Reservoir, assuming the reservoir was in place and 131,000 acre-ft of water were diverted from the reservoir each year, were reconstructed by mass balance for the 1931-77 water years. The reconstructed data may be used to predict future effects of a similar annual diversion of 131,000 acre-ft of water, assuming that future hydrologic conditions will be similar to historic hydrologic conditions.

Based on the analysis, the annual maximum end-of-month drawdown below the elevation at full storage would have averaged 54 ft. The maximum end-of-month drawdown below the elevation at full storage would have been 171 ft.

The mean-annual discharge-weighted dissolved-solids concentrations in the Colorado River near Glenwood Springs and Cameo, Colo., and Cisco, Utah, for the 1942-77 water years were computed for historic conditions and for conditions assuming an annual diversion of 131,000 acre-ft of water from Dillon Reservoir. The average increases in the dissolved-solids concentrations with the 131,000-acre-ft diversion were 15 to 16 mg/L at the three sites.

REFERENCES

Ficke, J. F., Adams, D. B., and Danielson, T. W., 1977, Evaporation from seven reservoirs in the Denver water supply system, central Colorado: U.S. Geological Survey Water-Resources Investigations 76-114, 170 p.

Harbeck, G. E., Jr., 1962, A practical field technique for measuring reservoir evaporation utilizing mass-transfer theory: U.S. Geological Survey Professional Paper 272-E, p. 101-105.

Knudsen, W. I., Jr., and Danielson, J. A., 1977, A discussion of legal and institutional constraints of energy-related water development in the Yampa River basin, northwestern Colorado: U.S. Geological Survey Contract Completion Report 14-08-0001-15075, December 1977, 20 p.

U.S. Department of the Interior, 1977, Final environmental statement, proposed Foothills project: Washington, D.C., v. 1 and 2.

U.S. Environmental Data Service, 1966-72, Climatological data, Colorado: Washington, D.C., U.S. Department of Commerce, annual summaries.

U.S. Environmental Protection Agency, 1976 [1977], Quality criteria for water: Washington, D.C., U.S. Government Printing Office, 256 p.

_____1977, National secondary drinking water regulations: Federal Register, v. 42, no. 62, Thursday, March 31, 1977, Part I, p. 17143-17147.

U.S. Geological Survey, 1954, Compilation of records of surface waters of the United States through September 1950--Part 9, Colorado River basin: U.S. Geological Survey Water-Supply Paper 1313, 749 p.

_____1964, Compilation of records of surface waters of the United States, October 1950 to September 1960--Part 9, Colorado River basin: U.S. Geological Survey Water-Supply Paper 1733, 586 p.

_____1961-74, Water resources data for Colorado--Part 1, Surface water records: Denver, annual reports.

_____1975-76, Water resources data for Colorado--Volume 2, Colorado River basin: Denver, Water-Data Reports CO-75-2 and CO-76-2.

_____1977, Water resources data for Colorado--Volume 2, Colorado River basin in Colorado, above the Dolores River: Denver, Water-Data Report CO-77-2.

U.S. Weather Bureau, 1930 and 1961-66, Climatological data, Colorado: Washington, D.C., annual summaries.

_____1954, Climatic summary of the United States, Supplement for 1931 through 1952, Colorado--Climatography of the United States: U.S. Weather Bureau Report 11-5, 62 p.

_____1964, Climatic summary of the United States, Supplement for 1951 through 1960, Colorado--Climatography of the United States: U.S. Weather Bureau Report 86-5, 86 p.

☆U.S. Government Printing Office: 1978 — 677-917/237